MULTIPLE PEAKS TRACKING FOR PHOTOVOLTAIC SYSTEM USING PARTICLE SWARM OPTIMIZATION WITH ARTIFICIAL NEURAL NETWORK ALGORITHM

NGAN MEI SHAN

UNIVERSITI TEKNOLOGI MALAYSIA

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NGAN MEI SHAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2013

Dedicated, in thankful appreciation for support, encouragement and understandings to:

My supervisor Dr Tan Chee Wei;

My husband Hong Pin;

My brothers Ngui Khiong and Ngui Lon;

Also to all my colleagues and individuals that contributed to this project.

ACKNOWLEDGEMENT

First I would like to express my greatest thanks to my supervisor, Dr. Tan Chee Wei for his guidance and advice in completing this project. I've been learned simple thing such as searching and reading the literature material until all those complicated hardware set up from him during my research study.

My particular appreciation goes to my husband and brothers who have been so tolerant and gives full supports toward me in order to complete this project. Thanks for their encouragement, love and emotional supports for all these while.

Finally, yet importantly, my appreciation goes out to all my colleagues in ENCON laboratory of FKE, my ex-course mates, my lecturers and whoever involved directly or indirectly in this project. My project would not be carried out so smooth without the aids and guidance from you all. Thanks you so much.

Thank You.

ABSTRACT

Photovoltaic (PV) array may receive different level of solar irradiance, such as partially shaded by clouds or nearby building. Multiple peak power points occur when PV module is under partially shaded conditions, which would significantly reduce the energy produced by PV without proper control. Therefore, Maximum Power Point Tracking (MPPT) algorithm is used to extract maximum available PV power from the PV array. However, most of the conventional MPPT algorithms are incapable to detect global peak power point with the presence of several local peaks. A hybrid Particle Swarm Optimization and Artificial Neural Network (PSO-ANN) algorithm is proposed in this thesis to detect the global peak power. The PV system which consists of PV array, dc-dc boost converter and a resistive load, were simulated using MATLAB/Simulink. The performance of the proposed algorithm is compared with that of the standard PSO algorithm. The proposed algorithm is tested and verified by hardware experiment. The simulation results and the experimental results are compared and discussed. It shows that the proposed algorithm performs well to detect the global peak of the PV array under partially shaded conditions. In this work, the tracking efficiency of the proposed algorithm is in the range of 96.8 % to 99.7 %.

ABSTRAK

Modul fotovoltaik (PV) mungkin menerima tahap sinaran suria yang berlainan, contohnya modul PV mungkin terlindung daripada sinaran cahaya oleh awan atau bangunan bersebelahan. Pelbagai titik puncak kuasa akan terhasil apabila modul PV berada dalam keadaan yang terlindung daripada sinaran cahaya, di mana situasi ini akan menyebabkan pengurangan penjanaan tenaga yang ketara. Oleh itu, algoritma Pengesanan Titik Kuasa Maximum (MPPT) digunakan untuk mengekstrak kuasa maximum fotovoltaik daripada modul PV. Walau bagaimanapun, kebanyakan algoritma MPPT yang konvensional tidak mampu mengesan titik puncak kuasa yang global daripada pelbagai titik puncak kuasa lain yang hadir. Satu algoritma hybrid yang menggabungkan Zarah Pengoptimuman Swarm dan Rangkaian Neural Tiruan (PSO-ANN) telah dicadangkan dalam projek ini untuk mengesan titik puncak kuasa yang global. Sistem PV yang terdiri daripada modul PV, pengubah arus terus dan satu rintangan telah disimulasikan dengan menggunakan perisian MATLAB/Simulink. Prestasi kaedah yang dicadangkan akan dibandingkan dengan prestasi algoritma PSO yang standard. Algoritma yang dicadangkan itu diuji dan disahkan dengan menggunakan eksperimen perkakasan. Keputusan simulasi dan keputusan eksperimen telah dibandingkan dan dibincangkan. Ia menunjukkan bahawa algoritma yang dicadangkan berprestasi baik untuk mengesan puncak global bagi modul PV yang berada dalam keadaan terlindung daripada sinaran cahaya. Di dalam kajian ini, kecekapan pengesanan algoritma yang dicadangkan itu adalah dalam lingkungan 96.8 % hingga 99.7 %.

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LIST OF SYMBOLS

GW	-	Giga watt
V	-	Voltage
A	-	Ampere
Ω	-	Ohm
W	-	Watt
kHz	-	Kilo Hertz
I_{ph}	-	PV current source
D, D1	-	Diode
R_{sh}	-	Shunt resistor
R_s	-	Serial resistor
I_D	-	Diode current
I_{sat}	-	Saturation current of diode
q	-	Quality factor
I_{cell}	-	Output current of a solar cell
I_{sh}	-	Shunt resistor current
V_{cell}	-	Output voltage of a solar cell
a	-	Thermal voltage
k	-	Boltzmann constant
e	-	Elementary charge
T	-	Temperature
J/K	-	Joule per Kelvin
I	-	Output current of a PV module
N_p	-	Number of solar cells in parallel
N_s	-	Number of solar cells in series

I_{SC}	-	Short circuit current
V_{OC}	-	Open circuit voltage
V_{max}	-	Maximum voltage
I_{max}	-	Maximum current
P_{max}	-	Maximum power
P_{MPP}	-	PV power at MPP
W/m^2	-	Watt per meter squared
θ	-	Zenith angle
AM	-	Air mass
kW_p	-	Kilo watt peak
MWh	-	Megawatt hour
$D(t)$	-	Duty cycle
ΔD	-	Perturbation step size
dP/dV	-	Change in power with respect to voltage
$\Delta I/\Delta V$	-	Incremental conductance
$V(k)$	-	PV output voltage at time k
$I(k)$	-	PV output current at time k
V_{MPP}	-	PV output voltage at MPP
k_1	-	Constant value for open circuit voltage method
I_{MPP}	-	PV output current at MPP
k_2	-	Proportionality constant for short circuit current method
E	-	Error
CE	-	Change in error
k	-	Sample time
$E(k)$	-	Error at sample time k
$P_{PV}(k)$	-	PV power at current sample time k
$P_{PV}(k\text{-}1)$	-	PV power at previous cylce sample time (k-1)
$V_{PV}(k)$	-	PV voltage at current sample time k
$V_{PV}(k\text{-}1)$	-	PV voltage at previous cylce sample time (k-1)
$CE(k)$	-	Change in error at sample time k
$E(k\text{-}1)$	-	Error at previous cycle sample time (k-1)
v_i^k	-	Velocity vector
v_i^{k+1}	-	New velocity vector

s_i^k	-	Position vector
s_i^{k+1}	-	New position vector
p_{besti}	-	best position found by particle *i*
g_{best}	-	best position found by particle group
w	-	inertia weight
c_1	-	cognitive coefficient
c_2	-	social coefficient
r_1	-	random parameter, [0,1]
r_2	-	random parameter, [0,1]
I_c	-	Initial PV current
ΔP	-	Change of PV power
I_{PV}	-	PV current
V_{PV}	-	PV voltage
G	-	Solar irradiance
p_{best}	-	best position
$I_{best\_particle}$	-	best current value within the search space
g_{best}	-	global best position
I_{best_swarm}	-	global best current value
$rand_1$, $rand_2$	-	Random numbers
v_c^{k+1}	-	Velocity of particle
I_c^{k+1}	-	Position of particle
$P(s_{i+1})$	-	PV power at current cycle
$P(s_i)$	-	PV power at previous cycle
V_t	-	Thermal voltage
V_D	-	Diode voltage
V_{PVcell}	-	PV cell voltage
L, L1	-	Inductor
Q, Q1	-	MOSFET switch
C, C_1	-	Capacitor
R_{load}	-	Resistive load
mH	-	miliHenry
μF	-	microFarad
k_p	-	Proportional coefficient

k_i	-	Integral coefficient
k_d	-	Derivative coefficient
µs	-	Micro second
$P_{PSO\text{-}ANN}$	-	Maximum PV power when PSO-ANN algorithm is implemented
P_{PSO}	-	Maximum PV power when PSO algorithm is implemented
P_{MPPT}	-	Maximum PV power when MPPT algorithm is implemented
E	-	Tracking efficiency
$E_{PSO\text{-}ANN}$	-	Tracking efficiency of PSO-ANN algorithm
E_{PSO}	-	Tracking efficiency of PSO algorithm
U_{OC}	-	Open-circuit voltage of the I-V curve
U_{mpp}	-	Voltage at the MPP
P_m	-	Currently measured DC power
U_m	-	Currently measured DC voltage
I_m	-	Currently measured DC current
MHz	-	Mega Hertz
I/O	-	Input / output
R_1, R_2	-	Resistor
$I_{F(AVG)}$	-	Average input current
mA	-	Milli-Ampere
V_{CC}	-	Positive voltage supply port for gate driver HCPL 3120
V_{EE}	-	Negative voltage supply port for gate driver HCPL 3120
V_{OL}	-	Voltage coefficient given in datasheet HCPL 3120
I_{OLPEAK}	-	Current coefficient given in datasheet HCPL 3120
t_{on}	-	Period for square pulse at maximum amplitude
t_{off}	-	Period for square pulse at zero amplitude
$+V_{dc}$	-	Positive voltage supply port for current transducer HY5P
$-V_{dc}$	-	Negative voltage supply port for current transducer HY5P
I_{in}	-	Input current
V_{out}	-	Output voltage
I_{PN}	-	Primary nominal current
I_{SN}	-	Secondary nominal current
R_p	-	Primary resistor

R_s , R_3	-	Output resistor
kΩ	-	Kilo-Ohm
+HT	-	Positive input pin for voltage transducer LV25P
-HT	-	Negative input pin for voltage transducer LV25P
V_{DS}	-	Drain-source voltage of MOSFET switch
V_{GS}	-	Gate-source voltage of MOSFET switch
V_{sensor_out}	-	Output voltage of voltage transducer
V_{sensor_in}	-	Input voltage of voltage transducer
I_{sensor_out}	-	Output current of current transducer
I_{sensor_in}	-	Input current of current transducer

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
MPPT	-	Maximum power point tracking
PSO-ANN	-	Particle swarm optimization and artificial neural network
MATLAB	-	Matrix laboratory
UNFCCC	-	United Nations Framework Convention on Climate Change
DC-DC	-	Direct current to direct current
DC-AC	-	Direct current to alternating current
P&O	-	Perturb and observe
Inc. Cond.	-	Incremental conductance
HC	-	Hill climbing
FLC	-	Fuzzy logic controller
GP	-	Global peak
LP	-	Local peak
MPP	-	Maximum power point
dSPACE	-	Digital Signal Processing and Control Engineering
PWM	-	Pulse-width modulation
PVAS1	-	Photovoltaic array string
BIPV	-	Building integrated photovoltaic
GaAs	-	Gallium Arsenide
A-Si	-	Amorphous Silicon
CdTe	-	Cadmium Tellunide
CIS	-	Copper Indium Diselenide
STC	-	Standard test conditions

SEPIC	-	single-ended primary inductance converter
MOSFET	-	Metal-Oxide Semiconductor Field-Effect Transistor
IGBT	-	insulated gate bipolar transistor
BJT	-	Bipolar Junction Transistor
GHG	-	Greenhouse gasses
FiT	-	Feed-in-Tariff
RPS	-	Renewable portfolio standard
TREC	-	Tradable renewable energy credits
SEDA	-	Sustainable Energy Development Authority
P-V	-	Power-voltage
iP&O	-	Improved perturb and observation
NB	-	Negative big
NS	-	Negative small
ZE	-	Zero
PS	-	Positive small
PB	-	Positive big
PSS	-	Power system stabilizer
MPSO	-	Modified particle swarm optimization
tansig	-	Tangent sigmoidal
logsig	-	Logarithm sigmoidal
purelin	-	Linear
IVMPPE	-	I-V curve maximum power point estimation
ESC	-	Extremum seeking control
MSE	-	Mean squared error
KCL	-	Kirchhoff's Current Law
RLC	-	Resistor / inductor / capacitor
PID	-	Proportional / integral / derivative
SISO	-	Single input single output
RAM	-	Random access memory
PC	-	Personal computer
GUI	-	Graphical user interface
DAQ	-	Data acquisition
ECU	-	Electronic control unit

RTI	-	Real time interface
RCP	-	Rapid control prototyping
HIL	-	Hardware in the loop
R&D	-	Research and development
PCI	-	Peripheral Component Interconnect
DSP	-	Digital signal processing
DRAM	-	Dynamic random access memory
USB	-	Universal serial bus
CPU	-	Central processing unit
RTIlib	-	Real time interface library
ADC	-	Analogue to digital converter
PCB	-	Printed circuit board
EMI	-	Electromagnetic interference
DAC	-	Digital to analogue converter

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent decades, the carbon dioxide levels in the atmosphere are rising at drastic rate with no sign of slowing, it results in global temperature continue to rise. The Kyoto Protocol, which was developed under the United Nations Framework Convention on Climate Change (UNFCCC) was came into force on 16, February 2005 mainly due to this reason. There were 191 states which have signed and ratified this protocol, where they agreed to reduce the emission of greenhouse gases (carbon dioxide, methane, nitrous oxide, hydro fluorocarbons, per fluorocarbons and sulphur hexafluoride) by 5.2 % on average for the period of 2008-2012 [1]. The environmental impacts caused by emission of greenhouse gases, the depletion of conventional energy resources (fossil fuels), and the continuous growth of energy demand from all around the world have urged the society to seek for alternative energies. Photovoltaic (PV) energy is one of the most promising renewable energy among the available alternative energies. PV energy is clean, inexhaustible and free to harvest. According to Renewables 2011 Global Status Report, PV energy is the world's fastest growing power-generation energy, which increases from 16 GW of PV capacity in 2008 to 40 GW of PV capacity in 2010 [2].

However, there are two major challenges that need to be tackled for a large scale PV system to be implemented: (1) high installation cost, (2) low efficiency in PV energy conversion [3]. Moreover, the PV output characteristics are nonlinear as it varies with solar irradiance and module temperature. Due to these characteristics, a maximum power point tracking (MPPT) controller is utilized to extract the maximum available power from PV array. The MPPT algorithm is used to control the duty cycle of the DC-DC or DC-AC converter which is inserted in between the PV modules and the load.

PV output exhibits a maximum power point (MPP) in their steady-state characteristics when it is under a uniform irradiance. It means that the solar irradiance varies uniformly in a period of time, where it does not change abruptly in a short time. Therefore, the MPPT algorithm takes certain time to search for the MPP and in turn the PV power stays constant in their steady-state. Over the years, numerous MPPT algorithms for PV array under uniform irradiance have been proposed. The widely used techniques include Perturb and Observe (P&O) [4-7], Incremental Conductance (Ind. Cond.) [8-9], Hill Climbing (HC) [5, 10], open-circuit voltage [10-11] and short-circuit current algorithm [10, 12]. Recently, several artificial intelligent methods, *i.e.* Fuzzy Logic Controller (FLC) [13-14], Artificial Neural Network (ANN) [13, 15] are explored.

Throughout the literature review [11-12], almost all of the MPPT algorithms have been developed for the PV arrays that are assumed to be varied under uniform solar irradiance and constant module temperature. However, the PV arrays might be partially shaded or illuminated by abruptly changing solar irradiance in real time practice. Other than that, partial shading scenario could also be created by shadow of trees, poles or buildings. PV cells which receive low illumination could be damaged by overheating problem which is known as hot-spot in PV partial shading condition, in which the greater current from other PV cells that are fully illuminated flow through the shaded cells. This problem can be overcome by inserting bypass diode across the PV cells [16]. However, the insertion of bypass diodes creates multiple peaks, namely global peak (GP) and local peaks (LP), which only the GP is the true

MPP on P-V characteristic curve. Therefore, in recent years, researchers tend to study and develop MPPT algorithms that are applicable to the PV arrays under partial shaded conditions.

1.2 Problem Statement

The conventional MPPT algorithms as mentioned in the introduction section, are not capable of tracking the true maximum power point if the PV array is partially shaded [17]. The conventional algorithms are not intelligent enough to differentiate among the global and the local peaks, where the control of operating point tends to linger around the local peaks. One of the solutions to search the global peak is by using a stochastic optimization method, where it is an optimization method that generates and uses random variables. The random variables involved the formulation of an objective function. The objective function is maximized or minimized according to the selected variables with random iterations. The searching of global peak is done by comparing the objective function of the variables used from point to point. Particle Swarm Optimization (PSO) is a method that is categorized as a stochastic optimization method, in which it can search along the multiple peaks of P-V characteristics within a large range. The searching of PSO method will cease when the stopping criteria set in the algorithm is met or else the PSO will keep on searching until it reaches the expected peak. Therefore, in this research, a hybrid MPPT method of Particle Swarm Optimization and Artificial Neural Network (ANN) is proposed to extract the global peak of PV characteristic curve under partial shaded condition. The ANN algorithm confines a smaller range of PV current as the initial inputs of PSO algorithm, which assists the PSO algorithm in searching the true global maximum power under the confined region.

1.3 Objectives

There are three main objectives for this project:

- To investigate the characteristics of photovoltaic generation under full illumination and partial shaded conditions.
- To design and control a stand-alone PV system with high tracking efficiency under partial shaded conditions.
- To verify the proposed MPPT algorithm experimentally.

1.4 Scope of the Project

This project focuses on the study of a stand-alone PV system, the investigation of the conventional MPPT algorithms and also the proposed hybrid MPPT method for the integration of PV power converters. The MPPT is tested with a power converter, where a boost converter is used in this project. The boost converter is designed for a maximum input voltage of 100 V and 3 A, where it is connected with a resistive load of 33 Ω, 300 W. There were two PV string array is used for the simulation, namely: six-series connected PV array and twelve-series connected PV array. Both of the PV strings are tested with standard PSO algorithm and the proposed PSO-ANN algorithm, where the MPPT algorithms are simulated by using MATLAB/Simulink software. The simulation results are observed and analysed. The hardware testing is carried out by using dSPACE – DS1104 R&D Controller Board and the built-up boost converter. Both the simulation and experimental testing are focused on the controlling of duty cycle of the boost converter by MPPT algorithm. In this research, the PV panels and the converter are not tested by sun-tracking algorithm, where the axis of the panels are tracked by motor powered single axis or two axes so that the PV panels receive maximum available solar irradiance. The simulation and experimental results are discussed and explained, so that at the end, the conclusion of this research is drawn.

1.5 Methodology

Firstly, literature review on a stand-alone photovoltaic system, the conventional MPPT algorithms for PV system under full illumination, and the proposed MPPT algorithm for PV system under partial shaded condition are studied. All the literature articles can be obtained from conference papers, journal papers, online articles and electronic books from internet or digital library in UTM. The literature review provides good theory and understanding about the PV system and the MPPT algorithms. The advantages and the disadvantages of each MPPT algorithm are reviewed so that the proposed MPPT method can be improved to overcome the shortcoming of the other MPPT algorithms.

The second step is to simulate the PV system with the proposed MPPT algorithm by using MATLAB/Simulink simulation software. The PV characteristics will be simulated by using this software. The knowledge about the PV characteristics from the literature reviews is justified through the simulation. The PV power curves also can be generated by the simulation, and it can be further analysed by hardware testing. The PV system is tested with standard PSO algorithm and the proposed PSO-ANN algorithm, where the simulation results of both MPPT algorithms are compared and analysed.

Upon the simulation, the experimental hardware is set up to test the proposed MPPT converter. The pulse-width modulation (PWM) of the boost converter with frequency of 50 kHz is generated by the MPPT algorithm in MATLAB/Simulink. The pulse signal is transferred to the hardware with Real Time Interface (RTI). The DC-DC boost converter is implemented together with a gate driver circuit, a voltage sensing circuit and a current sensing circuit. A single string PV array simulator (PVAS1) is used as the PV power-generation source for the boost converter.

Lastly, the PV power curve of the experimental hardware testing can be observed in oscilloscope or Control Desk which is the dSPACE experiment software for electronic control unit (ECU) development. The results of the hardware testing are analysed.

1.6 Thesis Structure

Chapter 1 describes the introduction of photovoltaic systems and the maximum power point tracking algorithms. It includes the problem statement of PV system, the objective of this thesis, the scope of this work and the methodology which is applied in completing this thesis.

Chapter 2 presents the fundamentals and types of PV systems, types of PV cells, PV characteristics and power converter. In addition to that, the building integrated photovoltaic (BIPV) technology and the PV system policy in Malaysia and worldwide are also introduced in this chapter.

Chapter 3 discusses various types of MPPT algorithm. The MPPT algorithms include: Perturb and Observe (P&O), Incremental Conductance (Inc. Cond.), Open-circuit Voltage, Short-circuit Current, Fuzzy Logic Controller (FLC), Particle Swarm Optimization (PSO), and Artificial Neural Network (ANN). The proposed hybrid PSO-ANN algorithm is explained in details in this chapter.

Chapter 4 details the simulation of PV module, dc-dc boost converter and MPPT algorithm using MATLAB/Simulink software based on the basic theory and the equations explained in previous chapters. The conduct of simulation and its simulation results are discussed and analysed.

Chapter 5 presents the hardware set-up for PV system testing, where the selection of the electronic components will be described in details. The hardware include: PV simulator, dc-dc boost converter, dSPACE – DS1104 R&D Controller Board, gate driver opto-coupler, current sensing circuit and voltage sensing circuit. The experimental results are discussed and analysed.

Chapter 6 draws the conclusions for this project based on the simulation and hardware results obtained, meanwhile the academic contributions obtained through this research are highlighted too.

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